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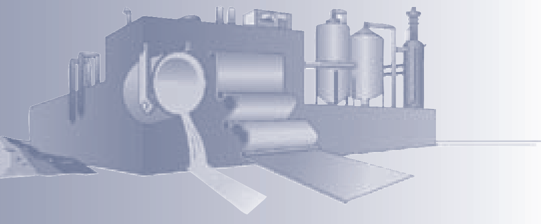

ISSUE FOCUS:
Unbalanced Voltage

IN THIS ISSUE

Updating compressed air system saves energy at winery. (page 5)

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Resolving Voltage Quality Problems with AC Induction Motors

By Doug Dorr, EPRI Solutions Inc., and Philip Lim, Memphis Light Gas & Water

Voltage nameplate ratings found on many alternating current (AC) motors and drives can be a source of confusion for utilities and their industrial customers. The confusion stems from the voltage range in which a particular motor may be operated safely. Additionally, voltage unbalance is known to create premature failure of heavily loaded motors if they are not properly derated. This article, the second and final article in our series that began with the Winter 2005 issue, discusses standards associated with AC induction motors and their nameplates and details a range of voltage quality issues that may warrant a problem-solving investigation.

AC induction motors support nearly every facet of industrial production. These workhorses of industry have been estimated to be part of the utilization of over half of the world's electric power generation. The AC induction motor typically has an inherent amount of tolerance to variations in utilization voltage as specified by the National Electrical Manufacturers Association (NEMA), however, utility power quality engineers can spend a great deal of time simply answering customer questions regarding proper utilization voltage for a given motor. While the motor can be operated with variations in the nominal voltage, it is important to understand all of the potential impacts on the supported process as well as on the motor itself.

The voltage quality related factors that tend to create the most serious problems in the field (and the most confusion) are nominal utilization voltage that does not match the motor nameplate, proper voltage sag ride through protection for the motor control circuitry, and phase-to-phase voltage unbalance. With these factors in mind, a systematic approach to investigating and resolving potential problems can be formulated.

Nominal Utilization Voltage

The U.S. standard for motor nameplate information can be found in the NEMA Standards Publication MG 1-2003: Motors and Generators. Motors meeting the criteria contained in the NEMA standard will operate satisfactorily within plus-or- minus 10% of the rated voltage. For example, if the voltage rating on the motor nameplate is 460 volts, that particular motor should operate safely when the utilization voltage is between 414 and 506 volts. However, as the voltage changes-even within the NEMA range-so will the torque, temperature, current, motor speed, and other motor characteristics. Additionally, any increase in operating temperature may accelerate the deterioration of the motor's electrical insulation system. Studies of operating temperature and its effect on insulation life suggest that a rise in steady-state operating temperature of 10 degrees Celsius can reduce insulation life by 50% or more. Table 1 shows some common motor voltages and the range in which the motors may be operated. Table 2 shows the effects of voltage variations on three-phase motors.

Table 1. Utilization Voltage Ranges for Induction Motors (Calculated based on the plus/minus 10% variation from rated voltage value specified in NEMA MG1)
{This table is not in MG1.}

Rated Motor Voltage (V)	Rated Motor Frequency (Hz)	Minimum Motor Voltage (90%)	Maximum Motor Voltage (110%)
110	60	99	121
115	60	104	126
200	60	180	220
208	60	188	228
220	60	198	242
230	60	207	253
300	60	270	330
380	60	342	418
440	60	396	484
460	60	414	506
575	60	518	632
2,300	60	2,070	2,530
4,000	60	3,600	4,400
4,600	60	4,140	5,060

(continued on page 2) ▶

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Resolving Voltage Quality Problems (continued from page1)

***** The plus-or-minus 10% voltage rating for AC induction motors assumes that the motor is operated at the nominal frequency. If the frequency is not the same as the nameplate frequency and in particular when 60-hertz motors are operated on 50-hertz systems, the sum of the percent of voltage difference and the percent of frequency difference from the nameplate ratings must not exceed10%. Values are approximate and voltages at or slightly above nominal are preferred for lower operating temperatures and higher starting torques.*

Table 2. General Effect of Voltage Variations on Characteristics of Induction Motors (from IEEE Std 141-1993)

Motor Characteristic	Voltage Variation	
	90% of Nameplate	110% of Nameplate
Starting and Maximum Running Torque	-19%	+21%
Percent Slip	+22%	-19%
Full-Load Speed	-0.2 to -1.0%	+2.0 to +1.0%
Starting Current	-10%	+10%
Full-Load Current	+5 to +10%	-5 to -10%
No-Load Current	-10 to -30%	+10 to +30%
Temperature Rise	+10 to +15%	-10 to -15%
Full-Load Efficiency	-1 to -3%	+1to +3%
Full-Load Power Factor	+3 to +7%	-2 to -7%
Magnetic Noise	Slight Decrease	Slight Increase

Voltage Unbalance

The second voltage quality related issue that the NEMA standard addresses is voltage unbalance. Unbalanced motor voltages may cause a current unbalance that in turn increases the operating temperature and energy losses of the motor. A voltage unbalance can magnify the percent current unbalance in the stator windings of a motor by as much as 6-10 times the percent voltage unbalance. When the voltage unbalance is more than 1%, derating the motor will help to mitigate the effects of the voltage unbalance. If the voltage unbalance exceeds 5%, it is not advisable to operate the motor at all—even when the motor has been derated. When a voltage unbalance exceeds 3%, the root cause of the unbalance should be identified and remedied. In cases where motor failures are occurring repetitively and the unbalance is greater than 1%, it may be prudent to investigate and resolve the root cause of the unbalance

Voltage unbalance must be treated separately from unusually low or high voltage conditions for three phase motors. As a matter of fact, both conditions in tandem would be a worst case condition for any motor, however there are a couple of sanity checks that can be performed to alleviate concerns (even when both voltage related problems are present). Provided that the motor nameplate current is not exceeded on any of the phase conductors and provided the actual motor speed is greater than or equal to the nameplate revolutions per minute (RPM), one can assume that detrimental affects on the motor are minimal. The condition under which the preceding statement would hold true would be that of a lightly (<50%) loaded motor. This is explained in more detail below, in the section on remedying voltage problems.

Voltage Related Symptoms

Symptoms of motor problems related to either voltage unbalance or to voltages not matching the nameplate rating are not always easy to diagnose because both the utility and facility distribution voltages vary as the system load and other system characteristics vary. Measuring the steady-state voltage at accessible points in the motor circuit is a very good way to determine whether a potential for voltage problems exists. A few symptoms that may trigger such an investigation include:

- Unusually high numbers of motor failures
- Not getting the expected motor life between rewinds
- Unexplained motor trips
- Motors that are more sensitive to voltage sags than other electrical process equipment
- Difficulty getting a specific motor started
- Nuisance tripping of a motor-protective device.

Additional possibilities beyond operating voltage and voltage balance can cause these symptoms. But the list provides a good starting point for deciding whether to conduct a voltage investigation.

Problem Solving Investigation

When a voltage quality problem with a motor is suspected, a proven procedure for investigating the problem is as follows:

Step 1. Find out enough information about the problem to determine whether the problem is isolated to one motor circuit or is common to the entire facility. This will help determine where to measure and possibly whether the source is internal or external. Develop a worksheet similar to the one shown in Table 3 to record circuit voltages (phase to phase/line to line for all phases), phase currents (using a true-RMS meter to detect the contribution of harmonics, if present), calculate unbalances and to record motor nameplate voltage, current, and revolutions per minute (RPM).

Step 2. Measure the voltage and current at accessible connection locations between the source transformer and the motor terminals. If the motor is three-phase, record voltage and current measurements for all three phases. If possible, obtain the measurements with the motor not running and also with the motor operating at its maximum steady-state loaded condition. Record the measured values in separate copies of the worksheet. For loads such as a chiller motor, it may also be useful to record steady-state voltages and currents at loading conditions other than full load. Don't forget to measure the coil voltages at the motor control circuit. It is very common to find that the motor tripping problems are associated with sags and low voltages at the control relay and starter coils for AC induction motors.

Table 3. Sample Motor Worksheet

Part One: Nameplate Data	
Voltage:	
Current:	
RPM:	
Part Two: Measurement	
Voltage, Phase A to B:	
Voltage, Phase B to C:	
Voltage, Phase C to A:	
Current, Phase A to B:	
Current, Phase B to C:	
Current, Phase C to A:	

Voltage Unbalance Percent =

$$\frac{\text{Maximum Deviation}}{\text{Average}} \times 100$$

Current Unbalance Percent =

$$\frac{\text{Maximum Deviation}}{\text{Average}} \times 100$$

Step 3. If the motor is three-phase, calculate the percent voltage unbalance using the following method. First, average the three voltages (the sum of phase A to B, phase B to C, and phase C to A divided by three). Then, select the phase-to-phase voltage that deviates most from the average. Determine the difference between the average voltage and the maximum deviation from the average. To determine the percent voltage deviation, multiply the difference times 100, and divide that number by the average. For example, if the measured voltages are 462, 465 and 447 volts: 461 + 465 + 447 = 1373; 1373/3 = 458. The greatest variation is 11 volts (458 – 447 = 11). 100 x 11/458 = 2.4% voltage unbalance. Repeat the calculation for percent current unbalance. For every 1% voltage unbalance, expect 6-10% current unbalance. Record both unbalances in the worksheet.

Step 4. If steps 1 through 3 reveal either 1) a motor current above the rated current, 2) a voltage unbalance above 1% that is not present when the motor is shut off, or 3) a utilization voltage outside the appropriate voltage range in Table 1, do the following before continuing:

- Inspect all motor circuit elements downstream from the mains disconnect, including contactors, connectors, and conductors.
- Ensure that all connectors have tight low-impedance connections, including those inside the motor connection box.
- Ensure that the connectors are compatible with the metallic conductor type used.
- Ensure that motor contactors are not seriously worn or deteriorated to a point where high resistance is present.
- Ensure that the motor circuit conductors are properly sized and all of the same conductor material and in similar condition.

If the voltage unbalance is greater than 3% while the motor is not running, then contact your local utility to determine the cause of the unbalance. If one or more problems were found from the above inspections resolve the problems and then complete Steps 1 through 4 before continuing to Step 5.

Step 5. If Steps 1 through 4 reveal a low voltage, high voltage, or voltage unbalance greater than 1%, consider the following remedies:

If the steady-state voltage is too high or too low:

If the motor utilization voltage is higher or lower than the plus-or-minus 10% specification, or if the user desires that the motor operate closer to the nameplate nominal voltage, several acceptable methods exist for increasing or decreasing the supply voltage. If you decrease the utilization voltage, remember that as the utilization voltage decreases, the susceptibility of motor starters and control circuits to voltage sags will increase.

Utilization voltages can be adjusted via no-load tap changers on existing step-down service transformers. However, changing these taps interrupts the power to all transformer loads. Therefore, entire processes within a facility must be shut down during tap changes. Additionally, changing the taps of the service transformer will affect terminal voltages throughout the plant, potentially changing voltages at equipment that do not require a different voltage.

Step-up or step-down transformers can also be used to adjust utilization voltages. Some transformers, such as the constant-voltage transformer, can also mitigate the effects of voltage sags on motor-control circuits. Another way to adjust a utilization voltage is to boost or buck the voltage with an autotransformer. The buck-boost transformer can be field-connected to increase (boost) or decrease (buck) a utilization voltage from 5-20%, depending on the way the primary and secondary windings are connected. Because only the secondary windings carry current in an autotransformer configuration, a buck-boost transformer may be rated as much as 10 times lower than a fully isolated two-winding transformer. And although buck-boost transformers are single-phase, they can be applied to most three-phase equipment by matching three single-phase transformers. Caution: the transformer impedances must all match when applying single-phase transformer in a 3-phase configuration.

If the voltage unbalance is high:

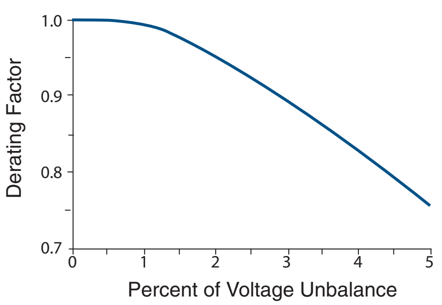
The root cause of the unbalance condition must be identified and the percent unbalance evaluated to determine what to do. There are a large number of possible causes for voltage unbalance, for example utility supply voltage unbalance, unbalanced single phase loads, high impedance connections, and malfunctioning voltage regulators. In many cases, the checklist from Step 4 above may uncover the root cause of the unbalance and lead to a fairly inexpensive solution. If the unbalance cannot be traced to an internal distribution element or to unbalanced single-phase loads in the facility, the local utility may need to assist by evaluating the percent unbalance of

(continued on page 4) ►

 (continued from page 3)

the distribution system, and the condition of the voltage regulation devices.

For a voltage unbalance of less than 1%, no remedial steps are necessary unless nuisance tripping or trouble during startup is associated with the unbalance. As the percent unbalance increases, the likelihood of problems increases. The NEMA standard for voltage unbalance states that a motor will operate satisfactorily at its rated load with a voltage unbalance up to one percent at the motor terminals. The American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE) C84.1 standard for nominal voltages implies that an adequately designed power system can have up to a 3% inherent voltage unbalance. However, if measurements at the motor terminals indicate more than a 1% voltage unbalance, the motor should be derated according to Figure 2.



Voltage Unbalance	Approximate Derating
1%	None
2%	95%
3%	88%
4%	82%
5%	75%

Figure 2. Derating Graph for Induction Motors Based Upon Percent of Voltage Unbalance

The derating curve in the figure can be applied to small and medium motors to minimize overheating. The curve assumes that the motor is already operating at its rated load. However, many motors do not operate at the rated load and are thereby in effect already derated.

A Motor Failure Case Study

An industrial customer called the local utility to report that the plant was experiencing excessive motor failure for no apparent reason. There was no history of motor failures so a utility voltage complaint investigator was dispatched to look into the problem. The customer's power is fed from a three-phase 750 kilovolt-ampere (kVA), 480Y/277 volt transformer. Because the motor failures were occurring on multiple circuits, the initial measurements were taken at the main service panel. Using the steps in the investigation procedure, a definite voltage unbalance was discovered inside of the facility. The measured voltages were:

- Phase A to B: 469.5 V
- Phase B to C: 503.3 V
- Phase C to A: 490.4 V

The average voltage from these readings was calculated to be 487.7 V, with the maximum voltage deviation from this average being 18.2 V (487.7-469.5)

The voltage unbalance at this facility was calculated to be 3.7% [(Maximum Voltage Deviation from the Average/Average) * 100]. This unbalance is above the level where we might expect internal loads and circuits to be the source of the problem.

Current measurements were then taken at the riser pole on the 12.47 kilovolt (kV) side (the feed to the customer's pad mounted 750 kVA transformer). The measured currents were:

- Phase A = 14.4 A
- Phase B = 16.1 A
- Phase C = 17.7 A

Using the formula [(Maximum Current Deviation from Average/Average)*100] the current unbalance for the facility was calculated to be 10.6%.

With the measured results in hand, a decision was made to focus the investigation on the utility source. An investigation of the circuit feeding the facility indicated that potential contributors to the voltage unbalance could either be a line voltage regulator (located 1.6 miles from the facility) or a set of power factor correction capacitor banks farther away. The voltage unbalance problem was explained rather quickly when the investigator read the settings on the line voltage regulator. The setting for A-phase setting was at position 12 buck (lower), B-phase setting at position 4 boost (raise), and C-phase setting at position 8 boost (raise). The voltage unbalance was caused by the malfunctioning of phase A and C regulators. Repairing the malfunctioning voltage regulators solved the problem. While this problem was fairly easy to resolve, the steps described in the investigation section proved useful in identifying the root cause.

A Motor Failure at a Polymers Plant

A polymers processing plant was experiencing an unacceptable number of process dropouts that plant engineers felt were electric power-induced problems. Plant personnel estimated the losses to be greater than $1 million a year with an average of 15 process dropouts annually. The plant was fed electrically from a 12.6 kV circuit prone to numerous types of problems ranging from cars hitting poles to animals faulting the power lines.

An investigation of the critical components at this plant indicated the majority of dollar losses were experienced when kill agents were dumped into the chemical reactors to stop the exothermic (heat generating) reaction. These kill agents are only used in an emergency if facility cooling water is lost due to the motors for the pumps and fans for the cooling process either failing or tripping off line. The result is approximately two weeks' worth of reduced grade (or out of spec) product while the residual kill agent works its way out of each stage of the process.

After discussing the problem with plant personnel it was determined that the kill agent would not have to be injected into the reactor if three critical cooling process components were maintained. These were the instrument control air compressors, the agitator motors for the reactor vessels and the cooling tower fans and pumps. At this particular plant, the voltage balance and nominal operating voltage level at the equipment were adequate, and it was suspected that voltage sags tripping the controls were the source of the problem.

Reviewing the utility's power quality data for voltage variations experienced at the substation feeding the plant indicated that about 90% of the sags were less severe than 50% of nominal voltage and did not last longer than about one-third of a second (20 cycles). Based on this information, it was clear that simply holding the critical process elements in for a half second or so would solve this costly problem.

Control circuit testing with a portable voltage sag generator confirmed the sensitivity of the control relay and motor starter coils to voltage sags. The facility's electrical maintenance group was provided with an overview of the identified problem and given a range of solutions that included pneumatic relays, constant voltage transformers and coil hold-in devices. Once they understood that holding in these processes momentarily would have no detrimental impact on plant or personnel safety they were eager to get the problem solved. The solution was a coil hold-in device that could be mounted in a standard relay socket next to the sensitive relays and starters. The coil hold-in device is connected between the AC source voltage and the coil of the relay or starter to be protected and substantially improves voltage-sag and tolerance. During a voltage sag condition, the device maintains a current flow through the coil sufficient to hold in the contacts. These coil hold-in devices are designed to protect the circuit from voltage sags, but are also designed to drop the circuit out if power is interrupted or if an emergency stop signal is applied.

Because the compressor required manufacturer approval before making modifications to the controls, it was recommended that the manufacturer be supplied with the range of options along with an explanation of the half-second hold in objective. The compressor manufacturer could then propose the best solution for their specific brand that would enable the facility to meet the hold in objective.

Motor power quality is a topic of concern to industrial customers and utility personnel alike. With a proper understanding of the impacts voltage quality may have on AC induction motors and a systematic investigative approach, most problems can be effectively and efficiently solved. As with nearly all power quality related problems, the solutions are simply a matter of having the proper tools and the know how to identify and isolate the root cause of the problem.

Of course having access to a device that can generate voltage sags on demand instead of waiting months for the next event to occur certainly helps out too!

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Performance Spotlight

Compressed Air System Upgrade Saves Energy and Improves Performance at a California Winery

In June 2004, Canandaigua Wine Company (CWC) completed an upgrade project on the compressed air system at its winery in Lodi, California. Before the project, the winery depended on two compressors to satisfy its production requirements. Anticipating an expansion of its production capacity, the winery commissioned a review of the compressed air system by a DOE Qualified AIRMaster+ Specialist at Atlas Copco Compressors, Inc. This review prompted a system-level improvement project that enabled the winery to employ its existing compressors more efficiently and to add a more efficient compressor than the company had originally planned.

Plant/Project Background

Established in 1945, CWC markets and sells 20 brands of wines and beverages. In March 2004, CWC became part of a new organization, Constellation Wines U.S., which is part of Constellation Brands. Within the new organization, CWC operates as an independent sales and marketing company. Before the project began, the Lodi facility was served by two 125-horsepower (hp) rotary screw compressors. Because an expansion of 6 million gallons per year (a 40% increase in output) was being planned, the existing compressed air system would have been unable to support the additional load. In a system audit, load patterns showed that the greatest amount of air that the process required was during the 3-month fall crush season. The existing compressors had to operate at full load during this season to support production. However, during the rest of the year, both units were operated at partial load, wasting energy.

The project to improve the compressed air system's efficiency included a proactive leak repair campaign, additional storage, and a new controls package. Because the existing compressed air capacity was greater than the capacity needed during the 9-month off-crush period, plant personnel decided to implement a recommendation to install a 75-hp variable-speed compressor. This new compressor is versatile enough to satisfy plant demand during periods of low use, and it can also effectively supplement the two 125-hp compressors to provide enough air to satisfy plant demand during the crush season.

Results

The compressed air system project at CWC's Lodi winery is yielding impressive results. Annual energy savings of 218,000 kilowatt-hours (kWh) and energy cost savings of $22,000 are projected, based on AIRMaster+ estimates and measurements of the system's energy use. Because fewer compressors now have to operate at any one time, compressor run times have decreased. This decrease is projected to result in annual maintenance cost savings of approximately $5,000. Factoring in a $22,000 rebate from Pacific Gas & Electric, the company's electric utility, total project costs will effectively be $33,000. With total projected annual cost savings of $27,000, the project will yield a simple payback of slightly more than 1.2 years.

Lessons Learned

When an industrial facility is retooled or about to undergo a production increase, its compressed air system should be reevaluated to determine whether the system is configured efficiently and whether additional compressors are necessary. Had the CWC plant simply added a fixed-speed 75-hp compressor, the system would have been less efficient because the new unit would have used a less efficient control strategy. Instead, plant personnel decided to install a variable-speed compressor that can adjust its output more closely to the system's demand. The choice of this compressor was inspired by a system-level evaluation that provided the plant with a comprehensive strategy to improve the system's efficiency. This resulted in significant annual savings for energy and maintenance while effectively supporting the production increase. Such an approach can be applied in a wide variety of industrial facilities that use compressed air.

Partner Profile

Mark Kiser, a sales/systems engineer with Atlas Copco Compressors, Inc., is an AIRMaster+ Qualified Specialist who has evaluated compressed air systems for more than 10 years. Mark's use of AIRMaster+ was instrumental in analyzing Canandaigua Wines'

(continued on page 6) ►

Performance Spotlight

(continued from page 5)

compressed air system data and validating the results of the project.

Qualified Specialists are industry professionals who identify cost-cutting and efficiency opportunities in industrial plants. Experienced professionals who complete a qualification training workshop and exam for specific DOE-developed software tools receive special designations, and can use these tools to help plants reduce costs, decrease maintenance and downtime, and improve productivity. The training recognizes and enhances a professional's expertise in the use of DOE's AIRMaster+ software tool, Pumping System Assessment Tool, Process Heating Assessment and Survey Tool, and Steam System Tools. For information, visit www.oit.doe.gov/bestpractices/software_tools.shtml.

Benefits

- Saves $27,000 annually in energy and maintenance costs
- Reduces annual energy consumption by 218,000 kWh
- Reduces maintenance requirements
- Achieves a 1.2-year simple payback

Spotlight Tip

Compressed air systems are found throughout industry, and can consume a significant portion of the electricity used by manufacturing plants. Therefore, when an industrial plant is expanded or retooled, the plant's compressed air system should be evaluated to ensure it is properly configured for the new production parameters.

Plant-wide Energy Savings Identified at Ford Motor Plant

The Ford Cleveland Casting Plant (CCP) in Cleveland, Ohio, used a two-part assessment methodology to identify significant cost savings opportunities. Its assessment used characterization (to identify components of the production processes that had the greatest savings potential), and inside-out analysis (to identify specific savings opportunities that maximized savings while minimizing capital costs.

When completed, assessment staff had identified 16 energy- and cost-saving projects for short-term consideration to address a variety of issues, including combustion, compressed air, water, steam, motor drive, and lighting system efficiency. These projects represented a total of $3.3 million a year in savings with corresponding annual energy savings of almost 18 million kilowatt hours (kWh) in electricity and nearly 139,000 million British thermal units (MMBtu) in fuel. The overall simply payback was less than 1 year.

In addition, two long-term projects were identified that together would represent another $9.5 million in cost savings, with energy savings of more than 600,000 MMBtu in fuel and more than 8 million kWh in electricity.

DOE's Industrial Technologies Program cosponsored the assessment through a competitive process. DOE promotes plant-wide energy-efficiency assessments that will lead to improvements in industrial energy efficiency, productivity, and global competitiveness, and will reduce waste and environmental emissions. In this case, DOE contributed $100,000 of the total $300,000 assessment cost.

The Ford CCP produces cast iron engine blocks and engine components for Ford plants throughout North America. The complex includes two engine plants, an aluminum casting plant, and a central power plant. The power plant distributes steam, compressed air, and electricity to four production plants—the core shop, mold shop, melt shop, and finish shop. Annual production is about 300,000 tons of finished iron products. The complex buys electricity, natural gas, water, coke, and steam.

Primary raw materials for the melt shop include scrap iron, scrap steel, coke, and limestone. Raw materials are fed into scaled-down blast furnaces called "cupolas." The plant has four operational cupolas, and typically operates three of the four at any one time. Generally, two cupolas produce gray iron and one produces nodular iron.

In the mold shop, sand is formed into molds to fashion the outer surface of the castings. Sand cores made in the core shop create hollow areas in the castings. Molten iron is poured into molds moving along a conveyor. Here the molds are cooled, knocked out, and cleaned. Finishing is accomplished with shot blasters, vibratory shakers, and manual air chipping hammers. After finishing and dry painting, the castings are inspected and shipped.

Assessment Goals

The goals of the plant-wide assessment were to reduce energy use, waste, and production costs through a series of specifically targeted initiatives. The approach consisted of two phases:

- Characterization, to identify the components of the production processes that have the greatest savings potential
- Inside-out analysis, to identify specific opportunities that maximize savings while minimizing capital costs. In this approach, the analysis begins with the equipment that actually manufactures the product, then works outward.

The assessment team used the principles of lean production to analyze the core, mold, and finishing shops. In the melt shop, the focus was on improving cupola design and performance, and on improving the material handling, air-pollution control, pumping, fan, cooling, and compressed air systems.

During the characterization phase, the assessment team used flow diagrams to indicate the magnitude and location of energy-use, waste generation, and production costs during the manufacturing processes. Using these maps, specific systems, equipment, and processes were targeted for detailed analysis to identify the most attractive savings opportunities.

Once systems were identified and prioritized according to savings potential, the assessment team used an inside-out approach to analyze each system for savings opportunities. When seeking to reduce energy costs, the assessment team analyzed in sequence manufacturing equipment and processes, energy distribution systems, primary energy conversion equipment, and utility services. To optimize waste reduction, the team began its analysis at the manufacturing processes, worked outward to waste treatment equipment, and ended at the waste disposal services. By looking for savings opportunities first at the heart of the manufacturing process and then working out toward the plant boundary, savings could be multiplied because distribution systems, energy conversion equipment, and waste treatment processes can be downsized or eliminated. Applying the inside-out approach can yield significant savings at minimal initial cost.

The advantage of this approach is that it capitalizes on manufacturers' knowledge of their products and processes. It also utilizes the expertise of the plant designers, schedulers, managers, equipment operators, and maintenance staff to reduce resource use and costs.

The table lists the project recommendations identified during the Ford CCP plant-wide assessment.

Implementing the short-term projects could save about 18 million kWh and nearly 139,000 MMBtu per year, plus reduce carbon dioxide emissions by about 63 million pounds per year. In addition, the assessment team identified two projects for long-term consideration, including installing a high-capacity cupola. Implementing these projects could save another $9.5 million a year and produce energy savings of more than 8 million kWh in electricity and more than 600,000 MMBtu in fuel.

Ford is continuing to implement projects that were identified in the plant-wide assessment program. By June 2004, 3 projects were complete and another 9 were in progress.

As of March 2005, 11 of the 16 projects identified in the PWA had been implemented with a realized cost savings of approximately $1.5 million a year. Three other projects were identified for improvement but have been delayed until capital funds can be allocated.

Other projects identified during the PWA are still viable but fall under the "long-term consideration" category.

To learn more about the plant-wide assessment program, visit the plant-wide assessment Web page at http://www.oit.doe.gov/bestpractices/assessments.shtml or contact the EERE Information Center at 1-877-EERE-INF (1-877-337-3463).

Assessment Recommendations at the Ford Cleveland Casting Plant

	Annual Savings				Project Cost	Simple Payback (yr)
Recommended Short-Term Projects	**Electricity (kWh)**	**Natural Gas (MMBtu)**	**Other Fuel (MMBtu)**	**Cost Savings**		
Reduce excess air in cupola blast air preheaters		64,000		$361,000	None	Immediate
Inspect, repair, and maintain steam traps			11,000	$54,581	None	Immediate
Use supersonic oxygen lancing to improve temperature profile in cupola	2,707,000		49,000	$465,509	$10,000	0.08
Optimize riser and grating sizes				$101,099	$5,500	0.08
Install adjustable flow vortex nozzles to reduce compressed air use	911,000			$396,908	$63,070	0.17
Insulate bare pipes				$54,417	$7,323	0.17
Replace 400-watt with 360-watt metal halide lamps	1,484,000			$57,867	$16,000	0.25
Fix leaks and repair insulation in preheated combustion air ducting	369,000	11,000		$115,800	$47,000	0.42
Upgrade ladle heating system		24,000		$132,000	$70,000	0.5
Use notched V-belts on belt-driven equipment	2,724,000			$106,225	$52,428	0.5
Oxy-fuel injection system for one cupola		-17,000	-27,000	$328,900	$186,000	0.58
Install cooling tower to eliminate once-through cooling for air conditioning units	-164,000			$468,119	$368,000	0.83
Install isolation values and automatic moisture traps to reduce air leaks on weekends and shutdowns	318,000			$138,764	$154,550	1.08
Install a cover and heat recovery system at ladle dry/preheat stations		11,000		$59,000	$100,000	1.75
Install VFDs on cupola forced-draft blowers	4,492,000	13,000		$246,800	$609,000	2.5
Install VFDs on cupola induced-draft blowers	4,922,000			$192,000	$624,000	3.25
Total for short-term projects	**17,763,000**	**106,000**	**33,000**	**$3,278,989**	**$2,312,871**	**0.71**
Recommendations for Long-Term Consideration						
Install a high-capacity cupola	8,000,000	365,000	239,000	$9,465,659	$24,800,000	2.58
Replace 400-watt mercury lights with 360-watt metal halide lamps	282,000			$11,508	$42,468	3.67
Total for long-term projects	**8,282,000**	**365,000**	**239,000**	**$9,477,167**	**$24,842,468**	**2.62**
Total for all projects	**26,045,000**	**471,000**	**272,000**	**$12,756,156**	**$27,155,339**	**2.13**

Ask the EERE Information Center

Information Center engineers and technical staff expertly answer a wide range of industrial efficiency questions, 11 hours a day, Monday through Friday. The Center also has access to industry experts around the country. Call the EERE Information Center at (800) 862-2086, or go to www.oit.doe.gov/clearinghouse/ for additional information.

Q: I work at a small plant with rising electricity costs, a steady thermal load and access to natural gas. My management wants to know more about cost, performance and potential applications for microturbine-based generating systems.

A: Microturbines are small gas turbines in the 25 kilowatt (kW) to 500 kW generating size range. They come prepackaged—with the combustion turbine, generator, controls, interconnection and protective switchgear included. The smallest units are not much larger than a refrigerator.

The California Energy Commission reports equipments costs in the $700 to $1,100 per kW range. Adding heat recovery increases the cost by $75 to $350 per kW. Installation costs vary but are in the neighborhood of 30% to 50% of the total equipment costs. Microturbines are most often used in cogeneration configurations where they supply heat and power to facilities with a combined electrical and thermal load. To date, most installations have been in office buildings, hotels and educational facilities.

The electrical generating efficiency of a microturbine is in the 20% to 30% range—where efficiency is defined as electrical British thermal unit (Btu) output divided by fuel Btu input. Efficiency is traditionally determined with respect to the *lower heating value* or LHV rating for the fuel. Electrical generating efficiency and power output fall off at ambient temperatures above 65º F and at altitudes above sea level. Most microturbines are compatible only with natural gas, but at least one available model may be equipped with gas or liquid fuel injectors to enable it to burn such gaseous fuels as propane, digester gas, flared waste gases from oilfields or livestock facilities, or liquid fuels including diesel and kerosene.

The economics of an installation are greatly improved when waste heat is used for water heating or low-pressure steam production. An overall fuel use efficiency of 70% to 80% is possible as over 50% of the fuel input energy can be beneficially used through applying waste heat recovery techniques. Operating and maintenance costs are in the range of $0.01/kWh to $0.015/kWh.

Coming Events

The following list contains only 10 of the 43 training opportunities that are currently scheduled and available to you and other plant personnel. For a complete listing, registration information, and updates, visit the BestPractices training web site at http://www.oit.doe.gov/bestpractices/training/textCalendar.shtml.

Fan System Assessment, Elko, NV, May 24, 2005
For more information, contact Doug Prihar at dprihar@mapnv.com or 775-753-3640

Fundamentals of Compressed Air Systems (Level 1), Salisbury, MD, May 25, 2005
For more information, Brandon Arnold at barnold@energy.state.md.us or 410-260-7206

Steam System Assessment, Norfolk, VA, June 6, 2005
For more information, Ike Flory at iflory@odu.edu or 757-683-6560

Pumping System Specialist Qualification, Amherst, MA June 8-9, 2005
For more information, contact Eric Winkler at winkler@ceere.org or 413-545-2853

Fan System Assessment, Tulare, CA, June 14, 2005
For more information, contact Gary Pikop at pikopgj@sce.com or 559-625-7127

Steam System Assessment, Moses Lake, WA June 14, 2005
Please register by phone, e-mail, or online: Phone: 509-335-2811; Email: emmps@wsu.edu; or Online: www.regonline.com/22742

Fan System Assessment, Irwindale, CA June 15, 2005
For more information, contact Chris Lydoff at chris.lydoff@sce.com or 626-812-7370

Steam System Assessment, Longview, WA , June 15, 2005
To register, please call, email, or go online: Phone: 509-335-2811; Email: emmps@wsu.edu; or Online: www.regonline.com/22742

Fundamentals of Compressed Air Systems (Level 1), Upper Darby, PA June 16, 2005
For more information, contact Len Bishop at llbishop@drawproservices.com or 610-395-1090

Pumping System Assessment, Knoxville, TN June 16, 2005
For more information, contact Joe Widner at joe.widner@alcoa.com or 865-594-4835

BestPractices

The Industrial Technologies Program's BestPractices initiative and its *Energy Matters* newsletter introduce industrial end users to emerging technologies and well-proven, cost-saving opportunities in motor, steam, compressed air, and other plant-wide systems.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

EERE INFORMATION CENTER

Do you have questions about using energy-efficient process and utility systems in your industrial facility? Call the Energy Efficiency and Renewable Energy (EERE) Information Center for answers, Monday through Friday 9:00 a.m. to 7:00 p.m. (EST).

HOTLINE: 877-EERE-INF
or 877-337-3463

DOE Regional Office Representatives

- David Godfrey, Atlanta, GA, 404-562-0568
- Stephen Costa, Boston, MA, 617-565-1811
- Brian Olsen, Chicago, IL, 312-886-8479
- Jamey Evans, Denver, CO, 303-275-4813
- Chris Cockrill, Seattle, WA, 816-873-3299
- Bill Orthwein, Philadelphia, PA, 215-656-6957

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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